Races of *Puccinia graminis* in the United States and Mexico During 1984

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ABSTRACT

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Oat stem rust was present in trace amounts throughout the United States in 1984. Disease development was generally more than a week later than the 40-yr average. Losses were light throughout the United States. The principal race in the United States and Mexico was NA-27, virulent on hosts with resistance genes *Pg*-1, -2, -3, -4, and -8. NA-27 made up 94 and 100% of the isolates from the United States and Mexico, respectively. No virulence was found in oat stem rust for hosts with genes *Pg*-9, -13, -16, or -a. Wheat stem rust was found in trace amounts in trap plots near Uvalde and Victoria in southern Texas in early April. Additional overwintering sites were found in nurseries at Giddings, TX; Quincy, FL; Tifton, GA; and Jeanerette and Crowley, LA; and in a commercial field near Kaplan, LA. Stem rust spread northward into the northern Great Plains by mid-June. Although stem rust occurred on some hard red spring wheat cultivars, they had adequate resistance to prevent the massive inoculum concentrations that developed in 1953 and 1954, and losses were nil. Race 15-TNM, virulent on plants with *Sr*17, was the most common virulence combination, making up 74% of the 870 isolates from 324 collections. The second most common race was 15-TNM, avirulent on hosts with *Sr*17, which made up 9% of the isolates. No virulence was found on wheat lines with genes *Sr*13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, and Wld-1.

Puccinia graminis Pers. has been a major pathogen of many small-grain cereals and forage grasses worldwide. Since the virtual elimination of susceptible barberry bushes from cereal-producing areas of the northern Great Plains, epidemics have been less frequent (6). Nevertheless, windborne uredospores resulted in devastating epidemics (5) of stem rust on wheat in 1935, 1937, 1953, and 1954 and on oats in 1953 in the northern Great Plains. To prevent such epidemics, resistant cultivars were developed that in turn may become susceptible to new pathogen races. Thus, a constant monitoring of changes in pathogen virulence has been a part of the program to avoid crop losses. The data from these surveys also provide information on the effects of changes in host resistance on pathogen frequency and distribution.

MATERIALS AND METHODS

Field surveys were made over a 21,000-km route covering the Great Plains and the Gulf Coast of the United States and northeastern Mexico. The surveys followed a preselected, generally circular route through areas where small-grain cereals are important and rust historically has been a problem. Checks for the presence of rust were made at commercial fields each 32 km or at the first field thereafter. Additional checks were made at experimental nurseries and wheat trap plots along the route. Whenever rust was observed in a field or nursery, leaves or stems bearing rust uredia from a single plant or cultivar were collected. These collections were supplemented by others furnished by cooperators throughout North America.

In 1984, field surveys were made in the following areas: southern Texas and northeastern Mexico (late March), southern Texas (early April), northern Texas and Gulf Coast states (late April), Oklahoma and Kansas (mid-May), Nebraska and South Dakota (mid-June), eastern Dakotas and Minnesota (early July), and the north central United States (late July and early August). Two spore samples were taken from each field uredial collection received at the laboratory. One portion was used to inoculate 7-day-old seedlings of a susceptible host (when the forma specialis was known) or a group of potentially susceptible hosts treated with maleic hydrazide to enhance spore production. Each culture was maintained in a separate clear-plastic chamber. After 12–14 days, up to four leaves either bearing or pruned to bear a single uredium were saved and reincubated to permit free uredospores to germinate. Uredospores were collected separately 3–4 days later from up to three uredia (each such collection an isolate); each uredium provided enough spores to inoculate a differential host series.

Spores suspended in a lightweight mineral oil were sprayed on plants, which were then placed in a dew chamber overnight at 18 C. Plants were then placed in a greenhouse at 18–28 C. Infection types were observed after 10–14 days.

The second sample of spores from each collection was bulked with those from other collections made in the same area at about the same time and was used to inoculate a "universally" resistant series.

***P. graminis* f. sp. *avenae*.** The differential host series consisted of oat lines with resistance genes *Pg*-1, -2, -3, -4, -8, -9, -13, -15, -16, and -a (3). The universally resistant series consisted of the host lines Saia (CI 7010), CI 7221, S.E.S. 52 (CI 3034), X-1588-2 (CI 8457), Kyto (CI 8250), MN 730358, and CI 9139. These lines have been selected over a period of years as resistant to stem rust.

Data derived from collections made in the United States were separated into groups corresponding to five ecological areas (Fig. 1A) on the basis of oat production, cultural practices, and geographic separation.

***P. graminis* f. sp. *tritici*.** The differential host series consisted of wheat lines with genes for *Sr*5, 6, 7b, 8, 9a, 9b, 9d, 9e, 10, 11, 13, 15, 16, 17, 36, and Tmp. Races were assigned using the code shown in Table 1. The universally resistant series consisted of lines with the host genes *Sr*22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, and Wld-1 and the cultivars Era, Cando, Olaf, Leeds, and Ward. These lines and cultivars have been selected over a period of years as resistant to stem rust.

Data were grouped into nine ecological areas (Fig. 1B). Area 1S has mainly fall-sown spring wheat; area 1N, mixed wheat types; area 2, mostly soft red winter wheat; area 3, southern hard red winter wheat; area 4, mostly soft red winter wheat and scattered barberries; area 5, mixed wheat types; area 6, resistant hard red spring and durum wheats; area 7, northern hard red winter wheat; and area 8, mostly highly susceptible soft winter and spring wheats and scattered barberries.

RESULTS AND DISCUSSION

Data from collections made from commercial fields and naturally occurring hosts were separated from those made in nurseries and plots. No data were included from collections made in or near known inoculated nurseries.

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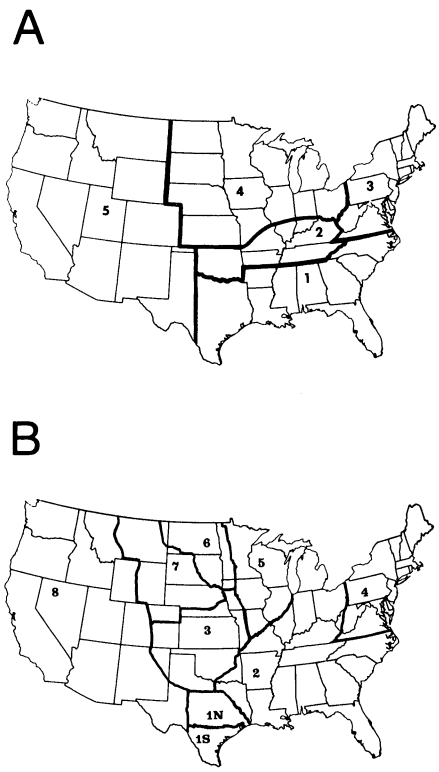

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for oat stem rust: (1) winter oats, (2) mixed winter and spring oats, (3) spring oats and barberry area, (4) major spring oat-producing area, and (5) widely isolated oat fields. **(B)** Areas for wheat stem rust: (1S) mainly fall-sown spring wheat, (1N) mixed wheat types, (2) soft red winter wheat, (3) southern hard red winter wheats, (4) mostly soft red winter wheat and barberries, (5) mixed wheat types and widely dispersed fields, (6) hard red spring and durum wheats, (7) northern hard red winter wheats, and (8) mostly soft winter wheats, spring wheats, and barberries.

Table 1. A key defining the Cereal Rust Laboratory races of *Puccinia graminis* f. sp. *tritici*

Code[a]	Response of host with *Sr* genes[b]			
Set 1:	5	9d	9e	7b
Set 2:	11	6	8	9a
Set 3:	36	9b	13	10
B	R	R	R	R
C	R	R	R	S
D	R	R	S	R
F	R	R	S	S
G	R	S	R	R
H	R	S	R	S
J	R	S	S	R
K	R	S	S	S
L	S	R	R	R
M	S	R	R	S
N	S	R	S	R
P	S	R	S	S
Q	S	S	R	R
R	S	S	R	S
S	S	S	S	R
T	S	S	S	S

[a] Combination of host responses from set 1 determines the first letter of code, set 2 the second, and set 3 the third.
[b] R = host not susceptible; S = host susceptible.

***P. graminis* f. sp. *avenae*.** Rust was first observed in early April in nurseries at Zaragosa and Anahuac, Mexico, and on wild oats in Yolo County, CA. No oat stem rust was found at Beeville, TX, until early May, nearly 4 wk later than the 40-yr mean (9). By mid-May, traces of stem rust were found in scattered locations throughout southern Texas and at Fairhope, AL. These areas provided inoculum for the northern oat-growing region, where rust occurred in light amounts. The initial infections sporulated by early June. Stem rust was found at Ames, IA, and Rosemount, MN, by early July. This outbreak was terminated by crop maturity before significant loss occurred.

Race NA-27 constituted 94% of the isolates collected in the United States (Table 2). This race has predominated in the U.S. population since 1965. NA-27 is virulent on hosts with resistance genes *Pg*-1, -2, -3, -4, and -8, but only *Pg*-2 and -4 are widely used in commercial cultivars. NA-27, however, has caused only one moderately severe epidemic (9). Race NA-16, which has been more common in the population obtained from wild oats and susceptible cultivars, was again the second most frequently identified race in 1984, making up 3% of the U.S. population. Race NA-5, which made up 2% of the population, is avirulent on lines with some of the earliest-studied resistance genes, *Pg*-1, -2, -4, and -8, but virulent on lines with *Pg*-15. Races NA-10, NA-23, and NA-24 were found in trace amounts. NA-10 occurred only in California, NA-24 was found both in Texas and Ontario, and NA-23 was detected only from wild oats in North Dakota. Virulence on lines with the single genes used for race identification is shown in Table 3. Hosts with genes *Pg*-9, -13, -16, and -a were resistant to the U.S. population sample in 1984; however, virulence to hosts with these genes has been found in the past. Only race NA-27 was obtained from collections of stem rust made in Mexico.

***P. graminis* f. sp. *tritici*.** Stem rust was

Table 2. Frequency of the identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1984

Area[a]	Source	Number of[b]		Percentage of each North American (NA) physiologic race[c]					
		Collections	Isolates	5	10	16	23	24	27
United States	Field	144	375	2	1	3	1	...	93
	Nursery	95	253	1	1	3	...	*[d]	94
	Total	239	628	2	1	3	1	*	94
1	Field	1	3	...	...	...	...	...	100
	Nursery	61	159	1	...	2	...	1	96
	Total	62	162	1	...	2	...	1	96
3	Field	1	3	...	...	...	...	...	100
4	Field	139	360	*	...	3	1	...	95
	Nursery	33	91	1	...	4	...	...	94
	Total	72	451	*	...	3	1	...	95
5	Field	3	9	67	33	...	...	...	...
	Nursery	1	3	...	100	...	...	...	...
	Total	4	2	50	50	...	...	...	...
Mexico	Field	2	4	...	...	...	...	...	100
Canada	Field	6	5	...	...	...	...	...	100
	Nursery	5	4	...	...	...	...	75	25
	Total	11	9	...	...	...	...	33	67

[a] See Figure 1A for ecological areas in the United States.
[b] Uredia from a single field, plant, or cultivar received separately was a collection from which up to three single-uredial isolates were identified.
[c] Martens et al (4).
[d] Less than 0.6% of the isolates.

Table 3. Incidence of virulence in *Puccinia graminis* f. sp. *avenae* isolates to the resistance of the single-gene differential lines in the 1984 survey

Area[a]	Percentage of isolates virulent on *Pg* gene[b]						
	-1	-2	-3	-4	-8	-9	-15
1	99	97	100	97	98	0	2
3	100	100	100	100	100	0	0
4	99	96	100	95	99	0	*[c]
5	0	50	100	0	0	0	100
United States 1984	97	96	100	94	97	0	3
United States 1983[d]	99	96	100	96	99	*	1
United States 1982[d]	95	89	100	88	89	0	5

[a] See Figure 1A for areas.
[b] No cultures were virulent on *Pg*-13, -16, or -a.
[c] Less than 0.6% of the isolates.
[d] Roelfs et al (7,12).

found in early April in wheat trap plots at Victoria and Uvalde, TX; and in early May in plots at Tifton, GA; Quincy, FL; and Jeanerette, Crowley, and Alexandria, LA; and in a commercial field near Kaplan, LA. Stem rust occurred in trace amounts in central and northern Texas by mid-May, from northern Kansas to southern Minnesota by the third week in June, and in east central North Dakota by early July. Disease development was restricted because resistant cultivars were sown in nearly all of the hard red spring and durum wheat areas. Disease onset was late in the southern Great Plains but near normal in the northern plains (3). Infections were found in commercial fields, but they were fewer than in 1983 (7) and little if any damage occurred. In 1984, 324 collections were obtained (Table 4), the second highest number since 1977 (7,10–12).

The most common race in the United States again was 15-TNM, constituting 83% of all isolates (Table 4); 74% of these were virulent on the differential host line with *Sr*17, and 9% were avirulent. A third member of the race 15 cluster (8), 15-TDM, which occurred only in area 4, was also avirulent on the line with *Sr*17.

The race 151-QCB and -QFB cluster was widely distributed but made up only 5 and 3% of the isolates, respectively. The third most common race cluster was 11-RCR, constituting 5% of all isolates. The earliest-stored culture of this race was obtained in 1956. It has appeared in only eight of the last 13 years and never has made up more than 5% of the isolates. Its prevalence in 1984 may have resulted from a high frequency of overwintering in the southeast, then a northward spread into area 4. Also found were races 113-RKQ, -RTQ, 17-HDL, -HNL, and 56-MBC. Race 113-RKQ consisted of the form virulent on plants with *Sr*17. The race 56 cluster varied for virulence on *Sr*Tmp (Table 4). An unusual race, 10-QCM, was identified from California that has virulence genes corresponding to resistance genes *Sr*5, 9a, 9d, 10, 15, 16, 17, 36 and additionally for *Sr*7a, 9f, 9g, 12, 18, 19, 20, 21, 23, and 28 (A. P. Roelfs and D. V. McVey, *unpublished*).

The collections from area 8 (Tables 4 and 5) were nearly all from the Pacific Northwest. They differed from collections from other areas in both virulence combinations (Table 4) and frequency of virulence (Table 5), presumably because of frequent sexual recombination and geographical isolation of the population.

Associations of virulence or avirulence

Table 4. Summary of the identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1984

				Percentage of isolates of each race[c]													
		Number of[b]		11	10	15			17	56		113		151			
Area[a]	Source	Collections	Isolations	RCR	QCM	TDM	TNM	TNM[d]	HNL	MBC	MBC[e]	RKQ[f]	RTQ	QCB	QFB	QSH	Others[g]
United States	Field	89	218	4	...	1	10	72	...	...	...	...	...	6	4	*	...
	Nursery	235	652	6	*[h]		8	75	1	*	1	*	*	5	2	*	...
	Total	324[i]	870	6	*	*	9	74	1	*	*	*	*	5	3	*	...
1S	Nursery	8	23	...	...	...	4	70	22	...	...	...	...	...	4	...	...
1N	Field	1	1	...	...	...	...	100	...	...	...	...	...	...	...	...	...
	Nursery	10	24	4	...	...	...	88	...	...	...	4	4	...	...	...	...
	Total	11	25	4	...	...	...	88	...	...	...	4	4	...	...	...	...
2	Field	13	38	...	...	...	5	71	...	...	...	...	...	8	13	3	...
	Nursery	60	172	20	...	...	6	51	...	...	...	...	*	17	4	...	...
	Total	73	210	17	...	...	6	55	...	...	...	...	*	16	6	*	...
3	Field	7	19	...	...	...	16	84	...	...	...	...	...	...	...	...	...
	Nursery	45	127	2	...	...	11	87	...	...	...	...	...	...	1	...	...
	Total	52	146	1	...	...	12	86	...	...	...	...	...	...	1	...	...
4	Field	13	36	17	...	8	8	25	...	...	...	...	...	30	11	...	...
	Nursery	3	9	33	...	...	...	33	...	...	...	...	...	33	...	...	...
	Total	25	45	20	...	7	7	27	...	...	...	...	...	31	9	...	...
5	Field	20	47	...	...	...	11	89	...	...	...	...	...	...	...	...	...
	Nursery	23	60	...	...	...	7	82	...	2	5	...	...	...	5	...	...
	Total	43	107	...	...	...	8	85	...	1	3	...	...	...	3	...	...
6	Field	33	71	4	...	...	14	82	...	...	...	...	...	...	...	...	...
	Nursery	81	225	...	...	...	11	88	...	...	*	...	...	...	...	...	...
	Total	114	296	1	...	...	11	87	...	...	*	...	...	...	...	...	...
7	Field	3	6	...	...	...	...	83	...	...	...	...	...	...	17	...	...
	Nursery	1	3	...	...	...	33	67	...	...	...	...	...	...	...	...	...
	Total	4	9	...	...	...	11	78	...	...	...	...	...	...	11	...	...
8	Nursery (Ca)	4	9	...	11	...	11	33	11	...	...	...	11	...	11	11	...
	Field (NW)	11	25	...	...	...	...	...	...	...	...	...	...	...	...	...	100
	Nursery (NW)	26	60	...	...	...	...	...	...	...	...	...	...	...	...	...	100
	Total (NW)	37	85	...	...	...	...	...	...	...	...	...	...	...	...	...	100
Mexico	Nursery	1	0	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Canada	Field	1	2	50	...	...	...	50	...	...	...	...	...	...	...	...	...
	Nursery	1	2	...	...	...	...	100	...	...	...	...	...	...	...	...	...
	Total	2	4	25	...	...	...	75	...	...	...	...	...	...	...	...	...

[a] See Figure 1B for description of areas.
[b] Uredia from a single field, plant, or cultivar received separately was a collection from which up to three single-uredia isolates were identified.
[c] Cereal Rust Laboratory races (Table 1).
[d] Virulent on *Sr*17.
[e] Virulent on *Sr*Tmp.
[f] Virulent on *Sr*17.
[g] The number of isolates for the other races found in Idaho, Oregon, and Washington (NW) were BBC (57), CBC (1), GBC (1), GCC (3), LBC (11), LCC (7), LFC (1), QFC (1), RBC (1), RHC (1), and SLC (1). All except the isolates of SLC and two isolates of LCC were virulent on *Sr*16. All except QFC were virulent on *Sr*17, all were avirulent on *Sr*Tmp, and only SLC was avirulent on *Sr*15.
[h] Less than 0.6% of the isolates
[i] Does not include 37 collections and 85 isolates from Idaho, Oregon, and Washington (area 8, NW) that were from a sexually reproducing population.

Table 5. Incidence of virulence in *Puccinia graminis* f. sp. *tritici* isolates to the resistance of single-gene differential lines used in the 1984 survey

Area[a]	Percentage of isolates virulent on *Sr* gene[b]														
	5	6	7b	8a	9a	9b	9d	9e	10	11	15	16	17	36	Tmp
1S	78	0	96	100	4	0	100	74	74	96	26	100	74	96	74
1N	100	8	100	96	12	12	100	88	100	92	12	100	96	100	88
2	100	1	78	77	39	18	100	61	78	61	39	100	93	78	61
3	100	0	99	99	2	1	100	98	99	98	2	100	88	99	98
4	100	0	60	49	20	20	100	41	60	40	59	100	76	60	41
5	100	0	97	96	3	0	96	93	97	93	7	100	92	93	97
6	100	0	100	98	1	1	99	98	100	98	2	100	89	100	98
7	100	0	89	100	11	0	100	89	89	89	11	100	89	89	89
8 (Ca)	89	22	67	89	33	22	100	44	78	78	56	100	67	78	44
8 (NW)	10	1	4	4	14	0	9	1	100	2	99	96	99	0	0
United States 1984	99	1	92	88	14	6	99	84	91	85	16	100	90	91	84
United States 1983[c]	94	1	90	90	6	2	94	88	95	88	12	100	77	90	77
United States 1982[c]	96	9	86	92	12	8	96	78	87	82	22	99	75	84	79
Mexico	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Canada	100	0	100	75	25	25	100	75	100	75	25	100	100	100	75

[a] See Figure 1B for areas.
[b] All isolates were avirulent on *Sr*13.
[c] Roelfs et al (10,12).

Table 6. Canadian race equivalents for Cereal Rust Laboratory races of *Puccinia graminis* f. sp. *tritici*

Cereal Rust Laboratory race	Canadian race[a]
10-QCM	C65(38)
11-RCR	C43(32)
15-TDM	C49(15)
15-TNM	C33(15B-1L)
15-TNM[b]	C53(15B-1L)
17-HNL	C2(17A)
56-MBC	C17(56)
56-MBC[c]	C17(56)
113-RKQ	C35(32-113)
113-RTQ	C41(32-113)
151-QCB	C56(38-151)
151-QFB	C75(38)
151-QSH	C25(38)

[a] Green (2).
[b] Virulent on *Sr*17.
[c] Virulent on *Sr*Tmp.

are common in asexual populations of *P. graminis* (1,8). These associations are important to know and understand when studying virulence or avirulence frequencies (Table 5) or when developing wheats resistant to stem rust. Virulence for *Sr*6 remains low although it is widely used in commercial cultivars in area 6. Resistance gene *Sr*17 is present in the commercial wheat cultivars in areas 3 and 6, and virulence has increased greatly in recent years from 20% in 1975 to 90% in 1984.

During the survey, no virulence was found to lines with *Sr*13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, or Wld-1. Virulence to host plants with *Sr*30 has occurred in the North America population of *P. graminis* f. sp. *tritici* but has not been detected since 1982 (12).

The data reported are from the southern three-fourths of the range of *P. graminis* f. sp. *tritici* in North America. The northern portion of the population is studied annually at the Agriculture Canada Laboratory at Winnipeg. This laboratory designates races differently (2), so equivalents are given for races reported in this paper (Table 6).

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